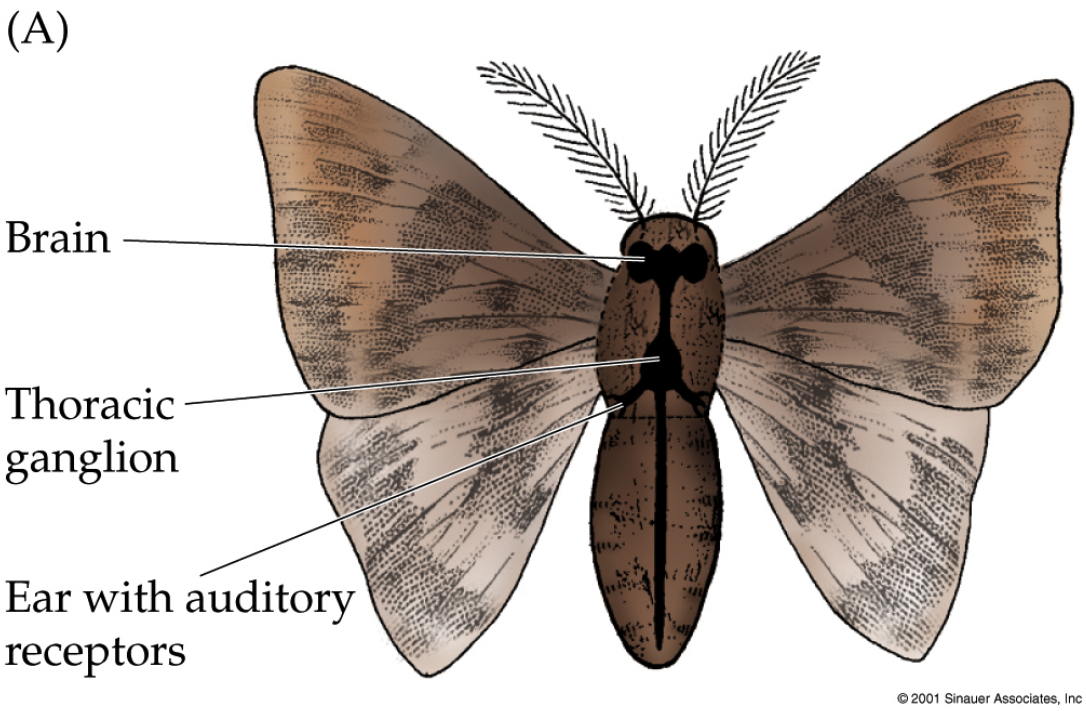
Coevolution

- Bats and prey
  - Passive hearing
  - Active sound producing
- Bats and plants
- Bats and parasites

Definition

- Coevolution: interacting species (prey/predator; host/parasite; consumer/producer) exert mutual selection and results in mutual adaptive evolution. May lead to evolutionary "arms race."
- Used to be viewed as common, but now thought to be uncommon
  - If species form tight associations, then extinction is likely due to population fluctuations.
  - May involve multiple species in diffuse association

Insects with ultrasonic hearing



Noctuid moth

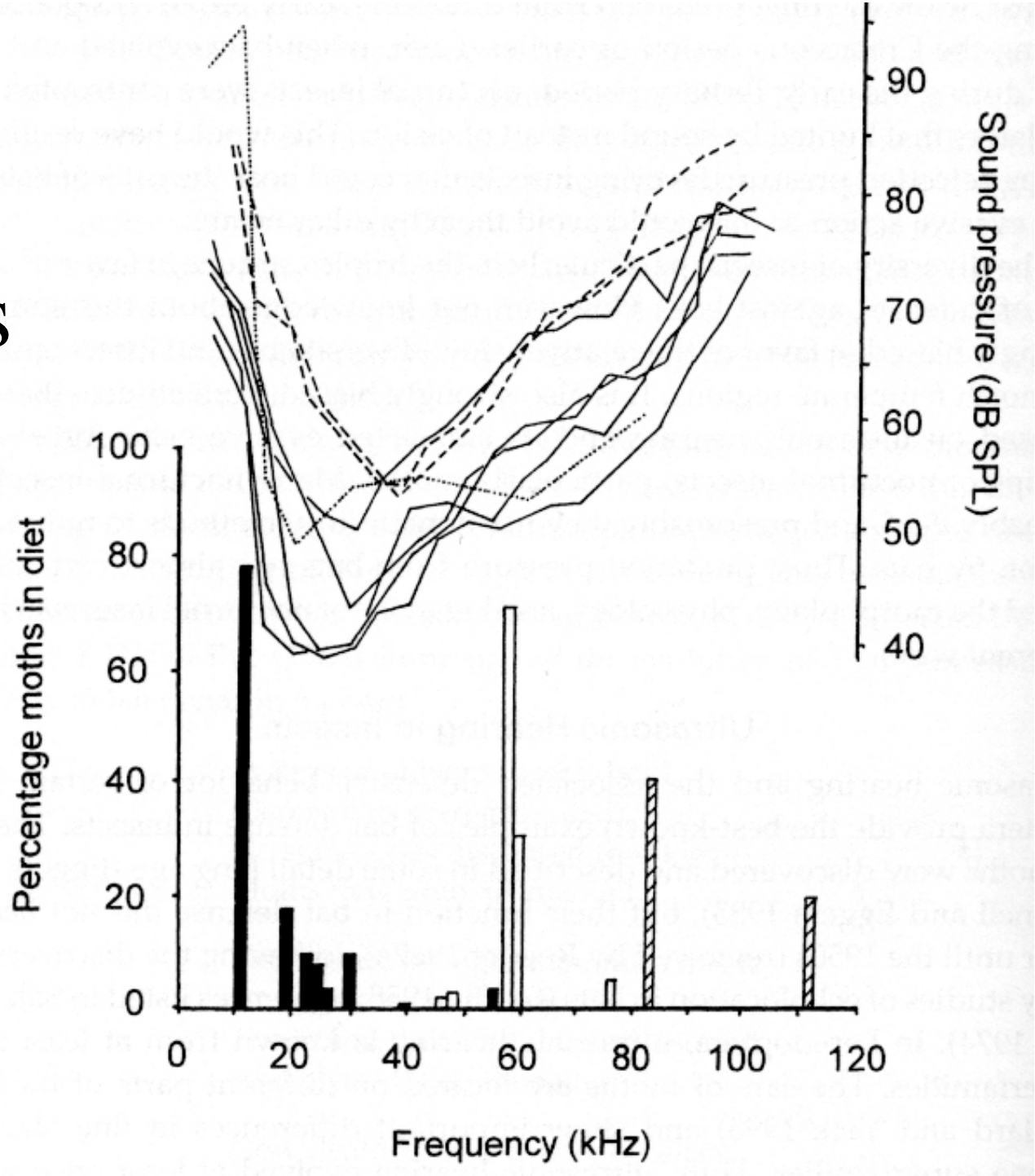
- Moths
  - Occurs in 7 superfamilies
- Beetles
  - Tiger beetles, scarab beetles
- Lacewings
- Preying mantis
- Locusts, crickets and katydids
  - Use for mate attraction
- Parasitoid diptera
  - Use it to find hosts

Moth audiograms

Best frequency of hearing by moths extends from 20-50 kHz

Moths are primary component of diet in bats that use calls below 20 or above 50 kHz.

High frequencies may be adaptation for moth hunting.



Moth evasive behavior

Response depends on call amplitude, i.e. bat distance.

Note that weak calls are unlikely to produce detectable echoes. Moths do not need rapid evasion unless call is loud.

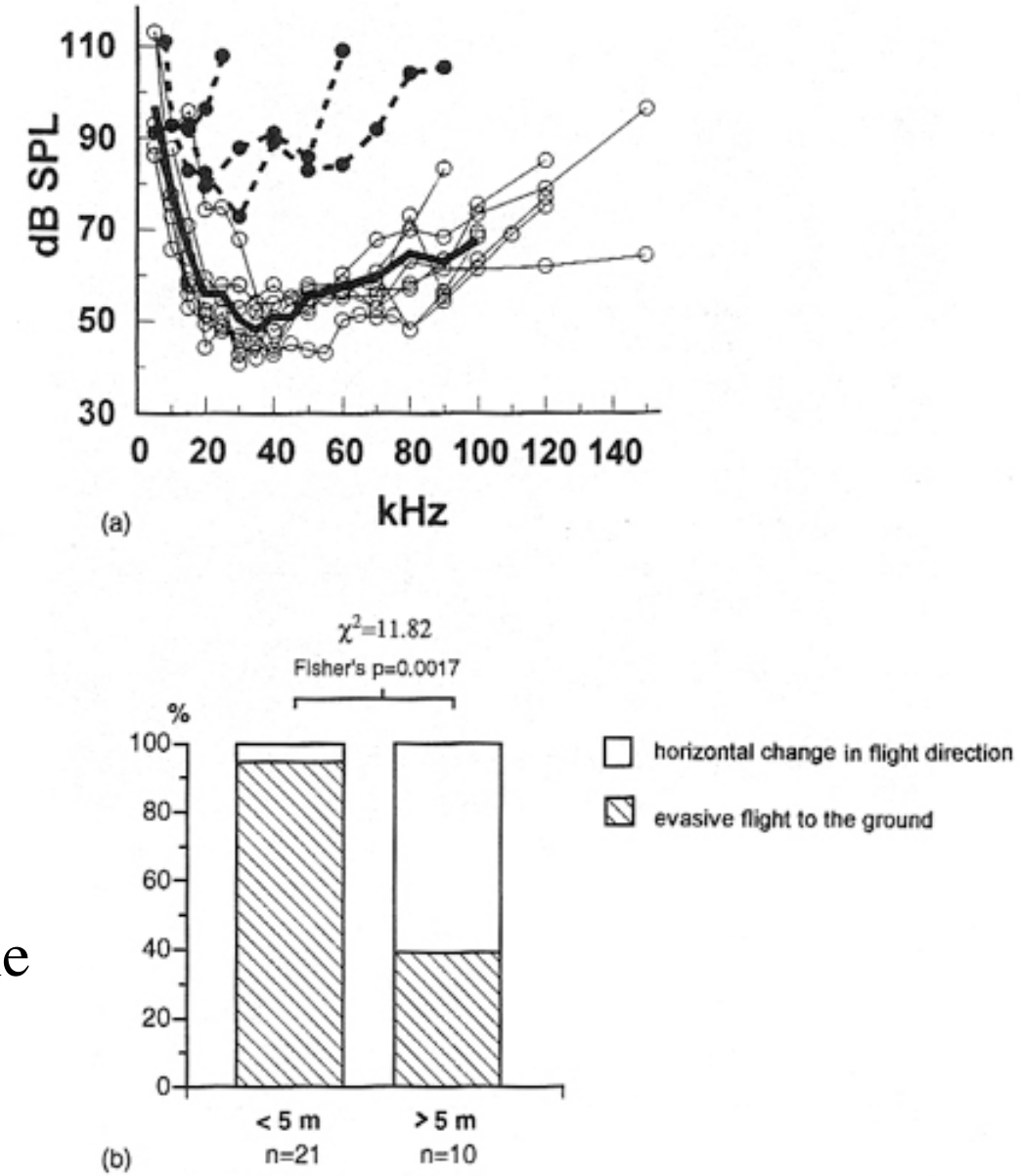
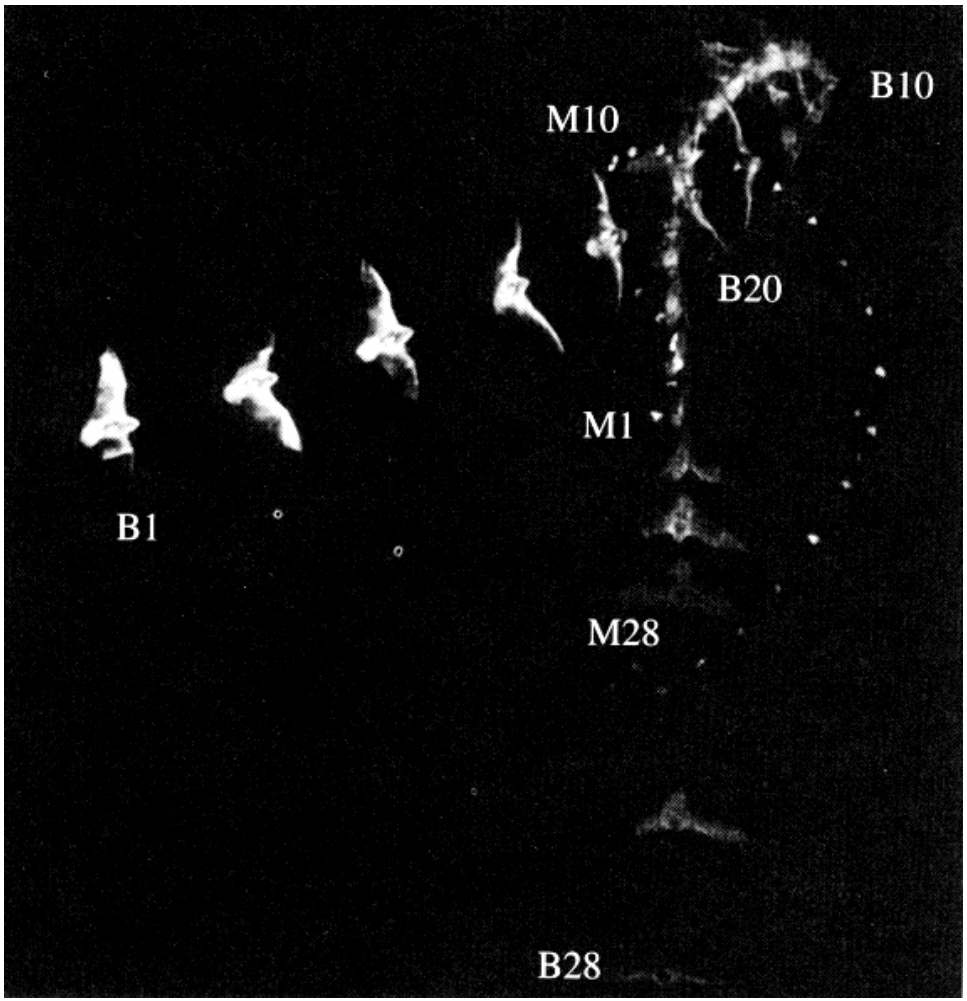


Figure 7.7. Bat defense in the geometrid moth *Agriopis marginaria* from Scandinavia, a species with fully winged males but flightless females. *a*, Audiograms of individual males (*open circles* and *solid lines; thick line* indicate mean threshold) and females (*filled circles* and *dotted lines*). *b*, Behavioral reactions of free-flying (wild) males to pulses of ultrasound (26 kHz, 110 dB SPL at 1 m) at various distances (<5 m and 5–12 m, respectively) from the sound source. (Modified from Rydell et al. [1997], with permission from the Royal Society.)

Moth evasive behavior



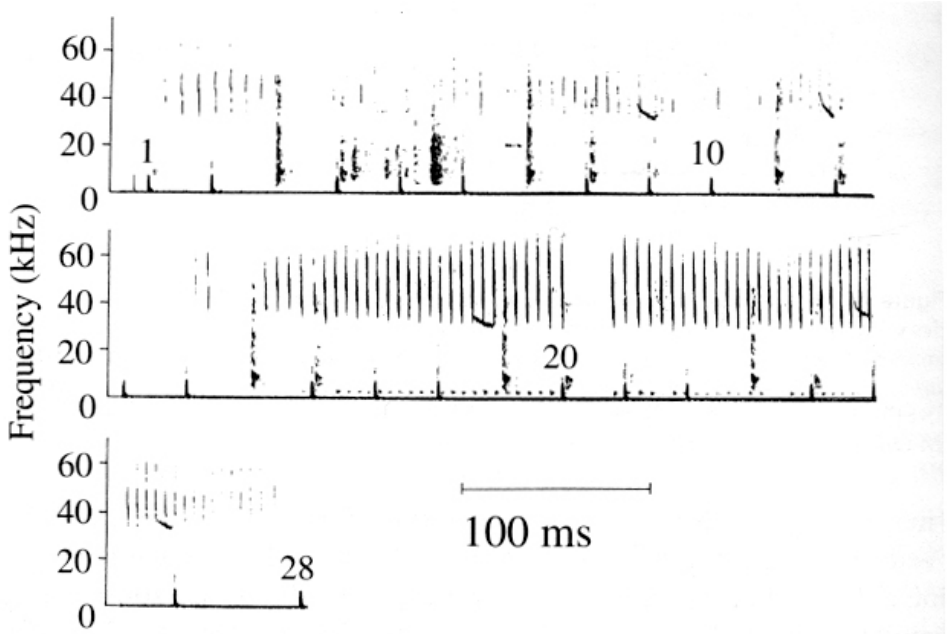
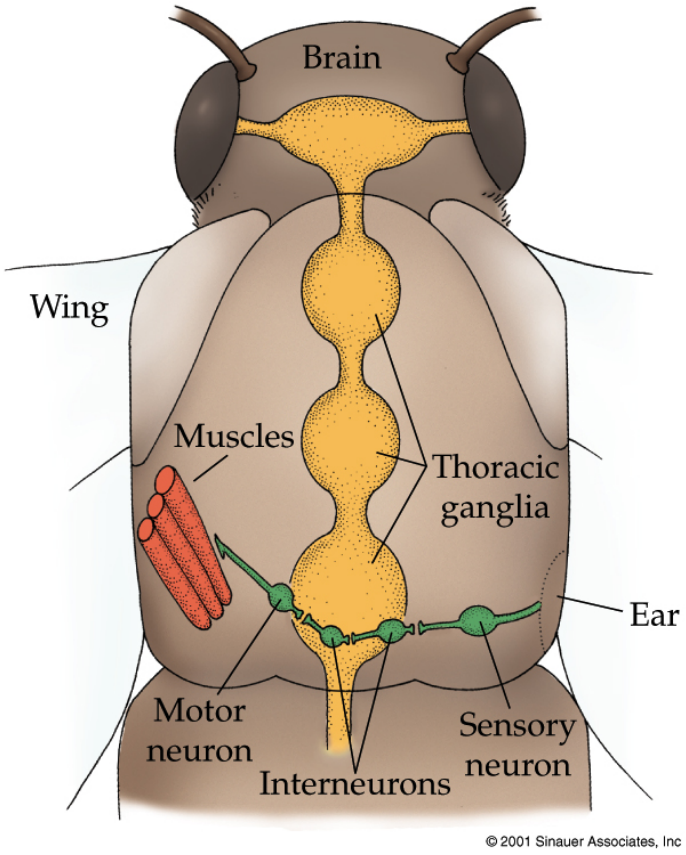
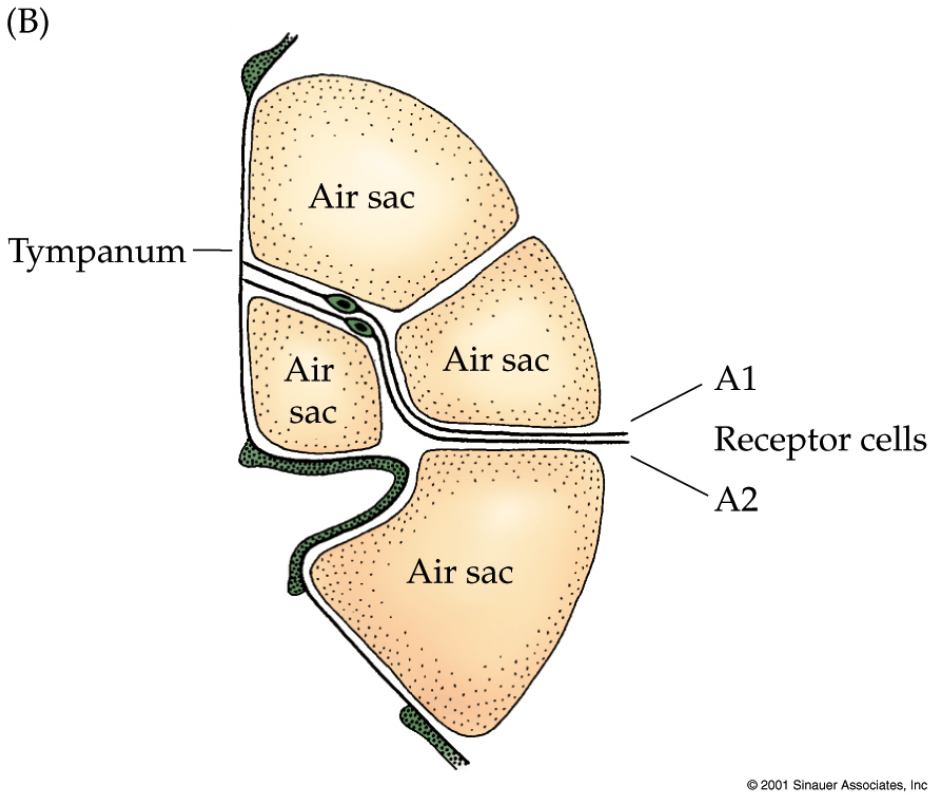


Figure 7.8. Photo of evasive response of a moth pursued by a red bat *Lasiurus borealis* in the field. The bat flies toward the moth, overshoots it, and by *B10* loops back toward the moth. At about *M12* (not shown in figure), the moth enters a power dive, and although it heads toward the bat's descending flight path, the bat again overshoots it and fails to capture the moth. Throughout the pursuit, the bat emits a prolonged terminal buzz (sonogram) in an attempt to track the moth. Images of the bat (*B*) and moth (*M*) are labeled chronologically, so the bat was at *B10* when the moth was at *M10*, 333 ms into the sequence. Flash rate was 30 Hz. The low frequency clicks on the sonogram are flash synchronization pulses. The search phase echolocation calls of a second bat can sometimes be seen in the background on the sonogram.

Noctuid moth ears





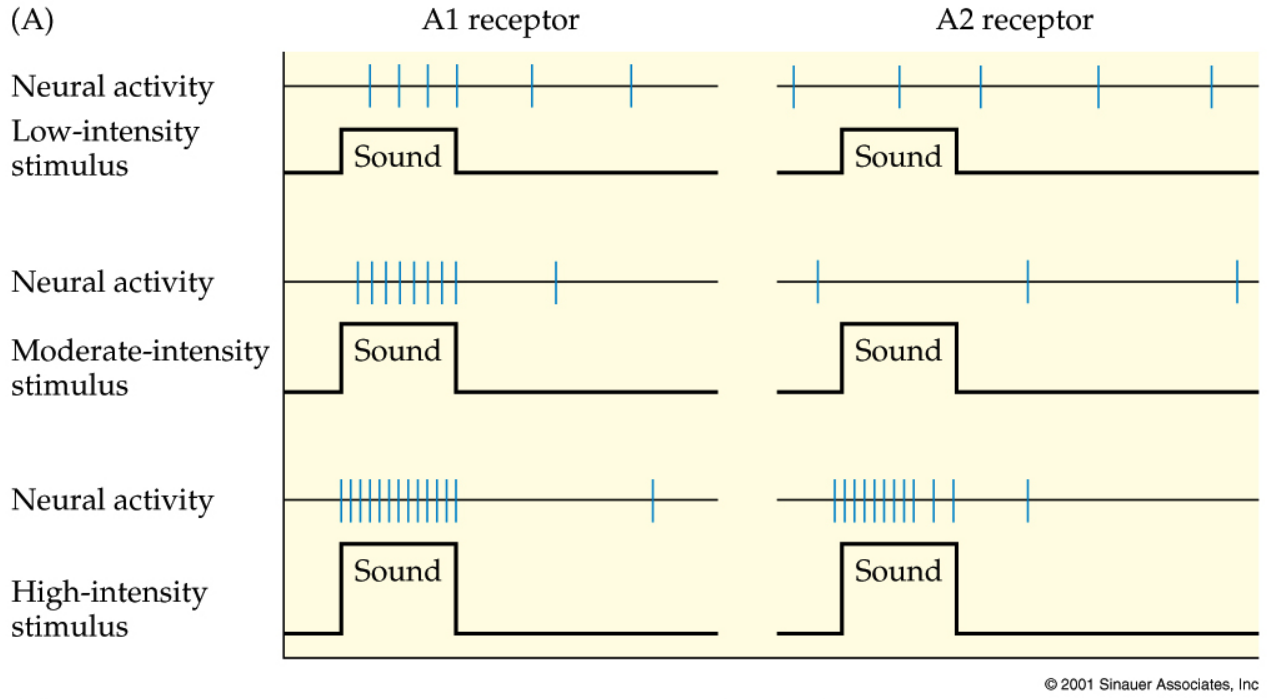
Muscle response is hard-wired.

Responses of A1, A2 receptors

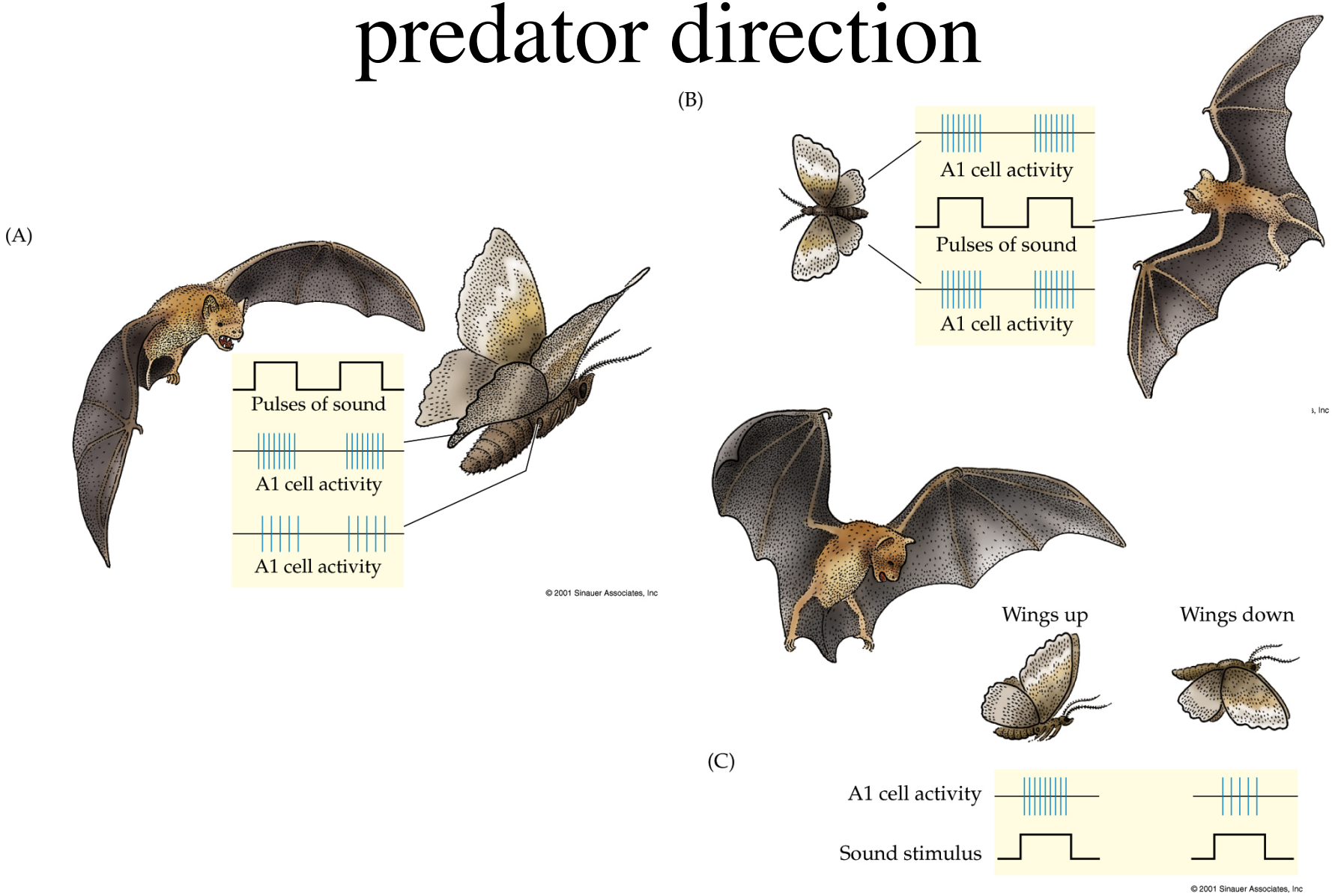
A1 receptor exhibits response to low intensity sounds. Causes moth to veer away from sound. Can detect little brown bat at 30 m. Pulse rate increases with amplitude.

A2 receptor only fires to loud sound. Causes moth to go into powerdive.

A1 receptor habituates to constant sound



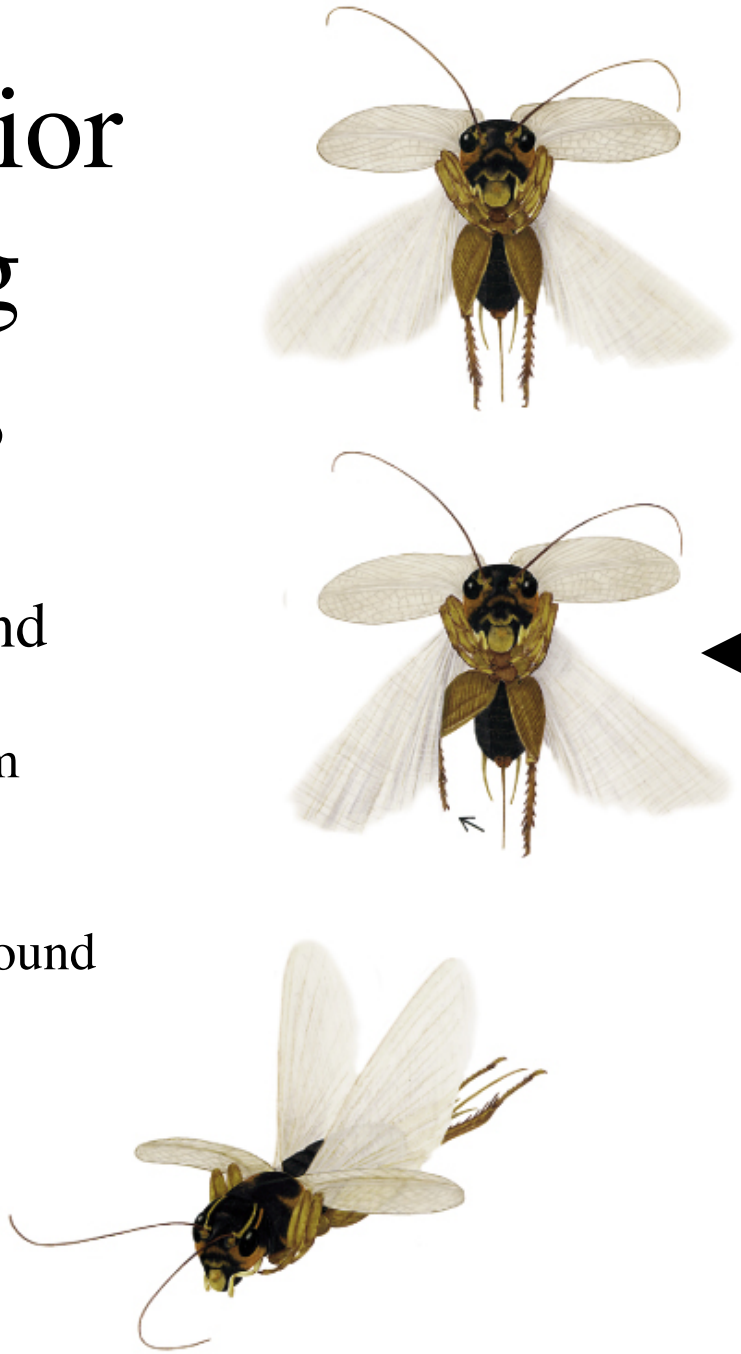
A1 response asymmetry indicates predator direction



Escape behavior involves leg movements

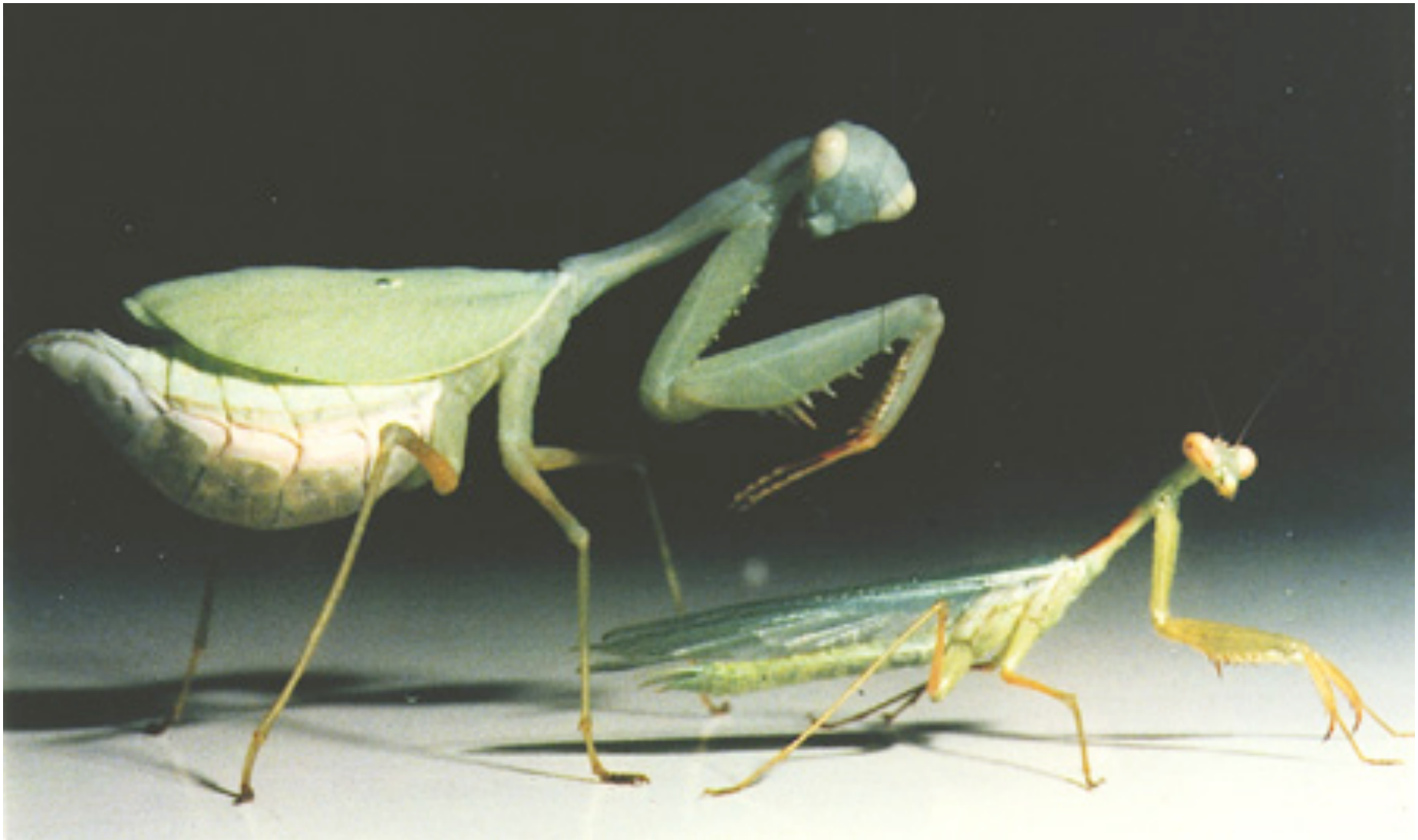
Cricket response to ultrasound

Lifts leg on opposite side from the direction of sound which causes wing beat to slow and the animal veers away from sound

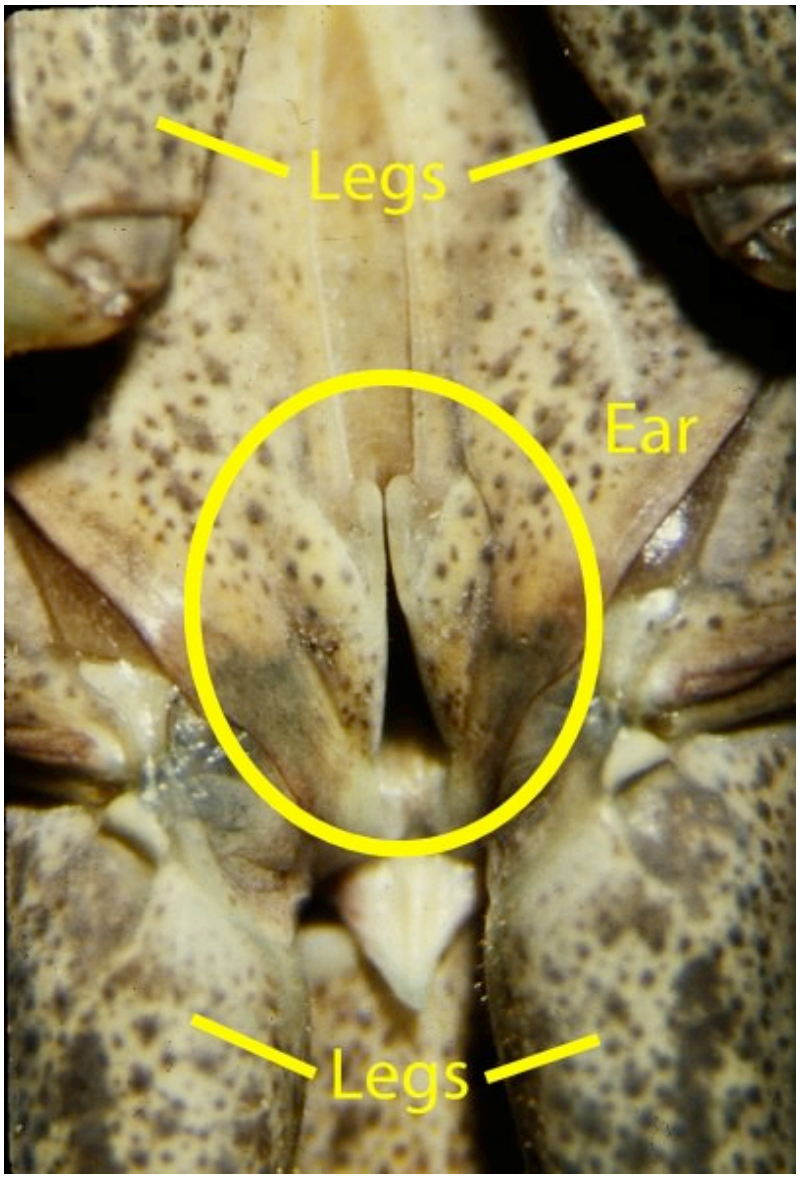


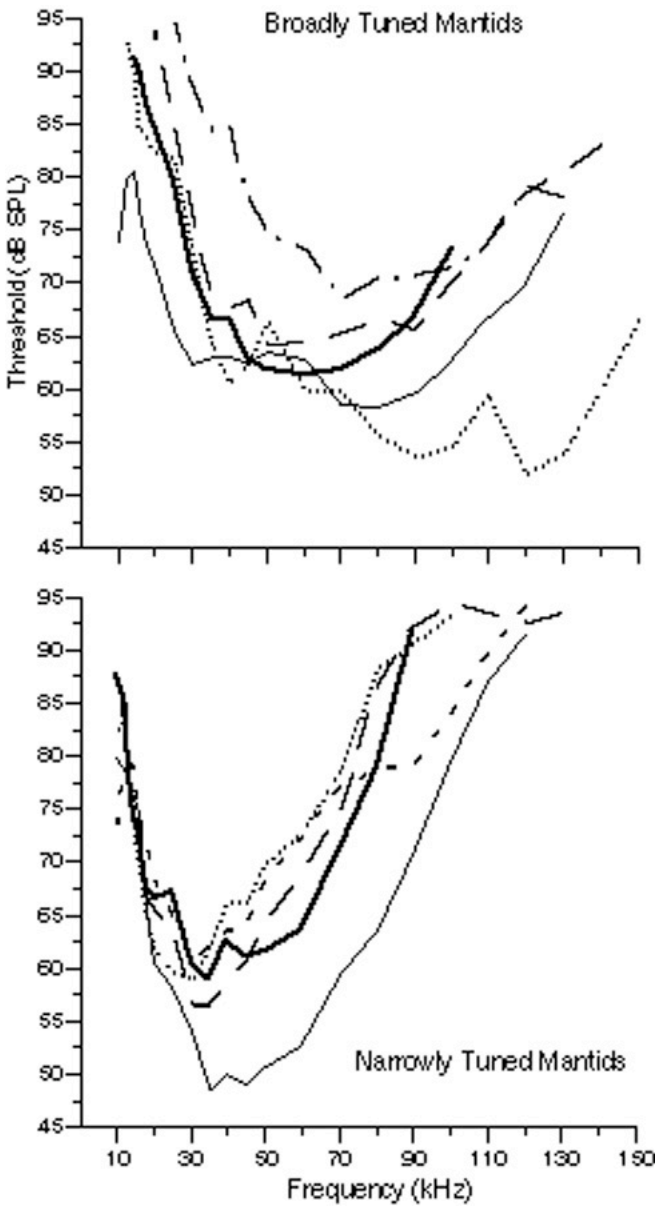
Ultrasound

Preying mantis exhibit dimorphism

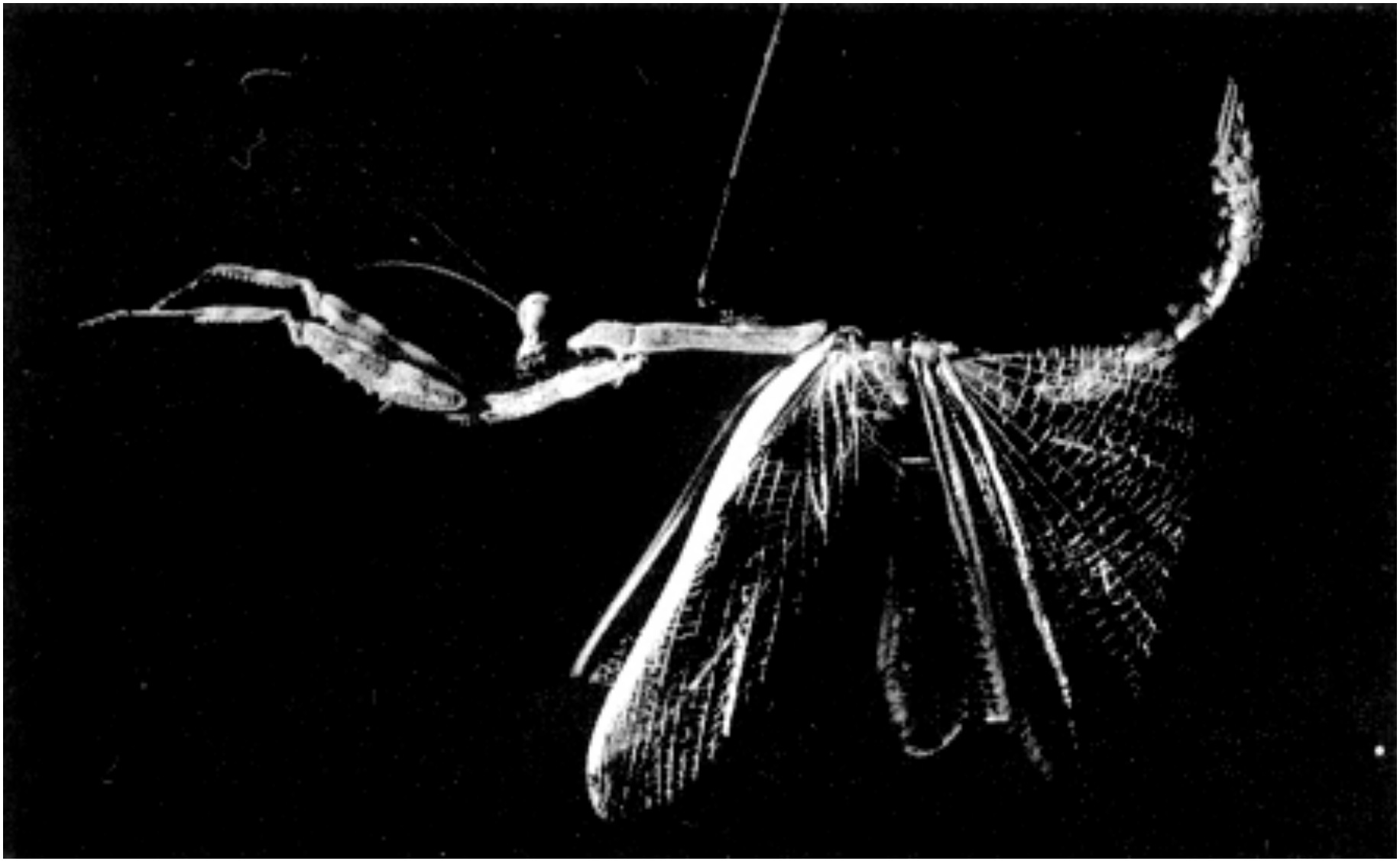


Flying mantids hear ultrasound

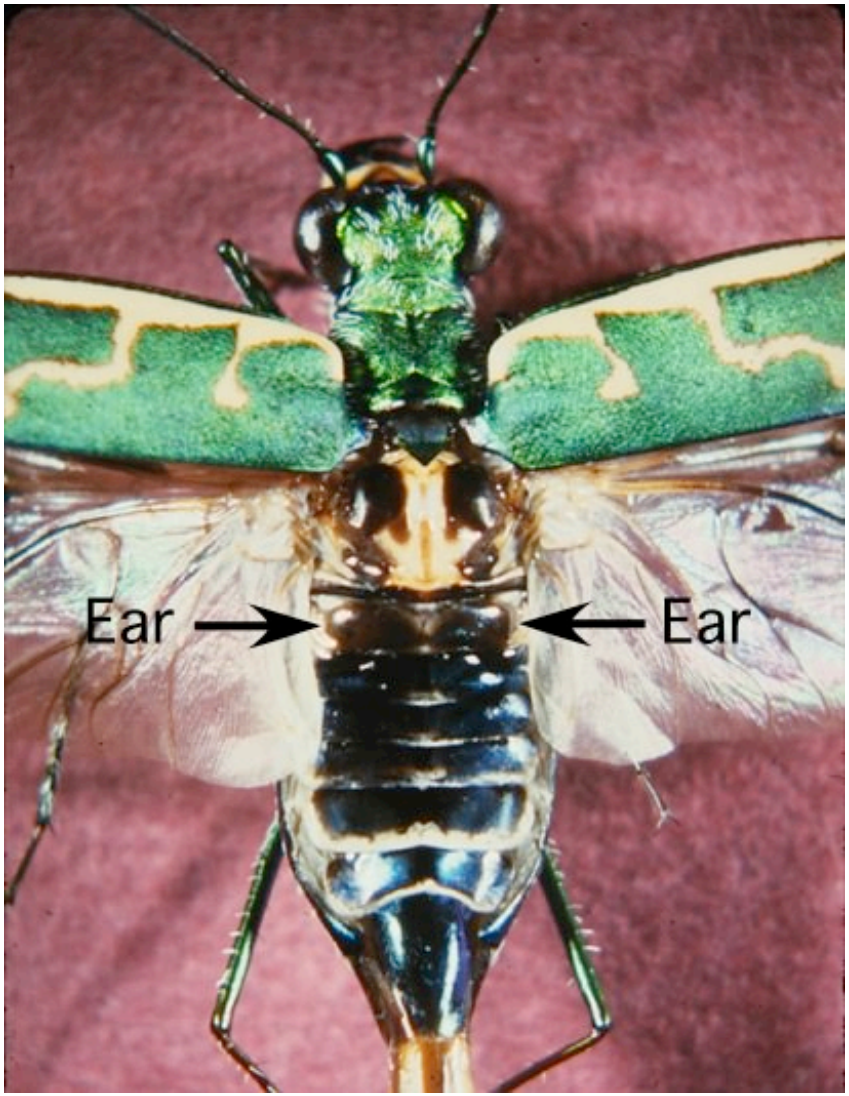


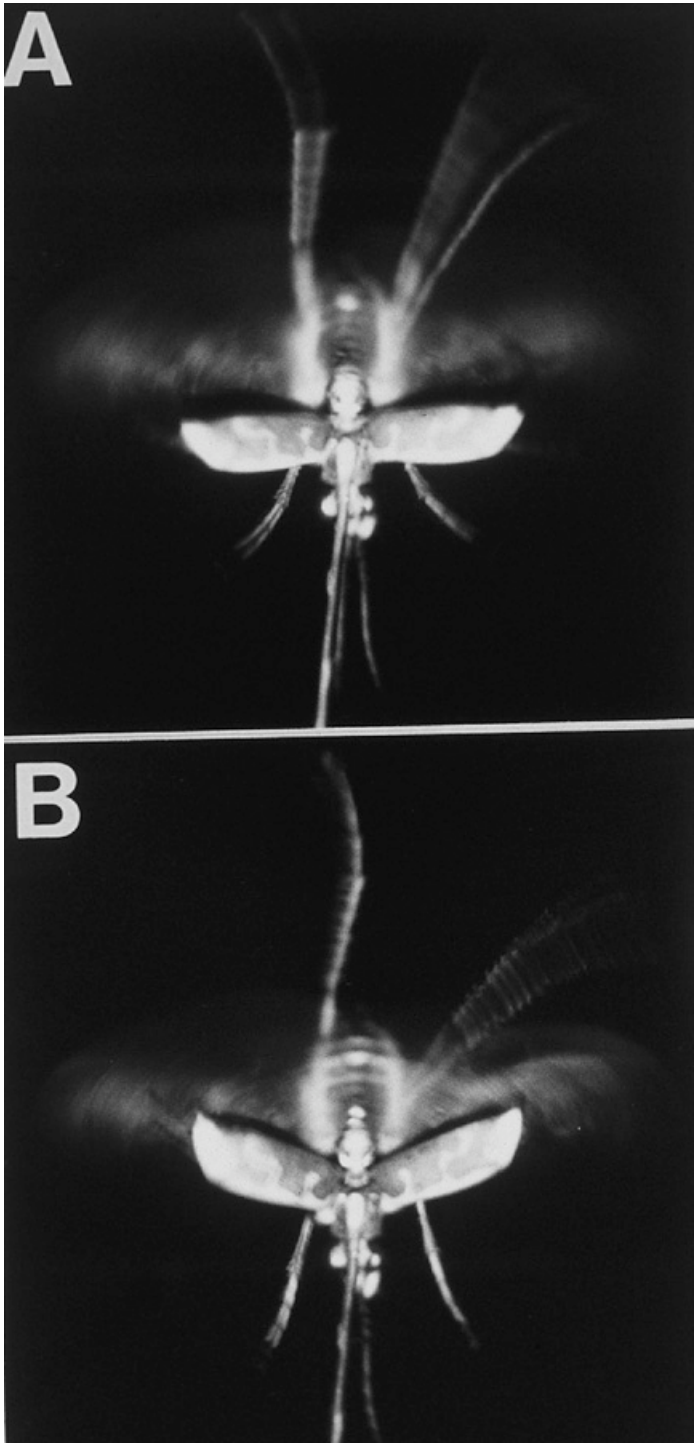


Response to ultrasound



Tiger beetle ears and escape behavior





Moths also modify display behavior to avoid bat predation

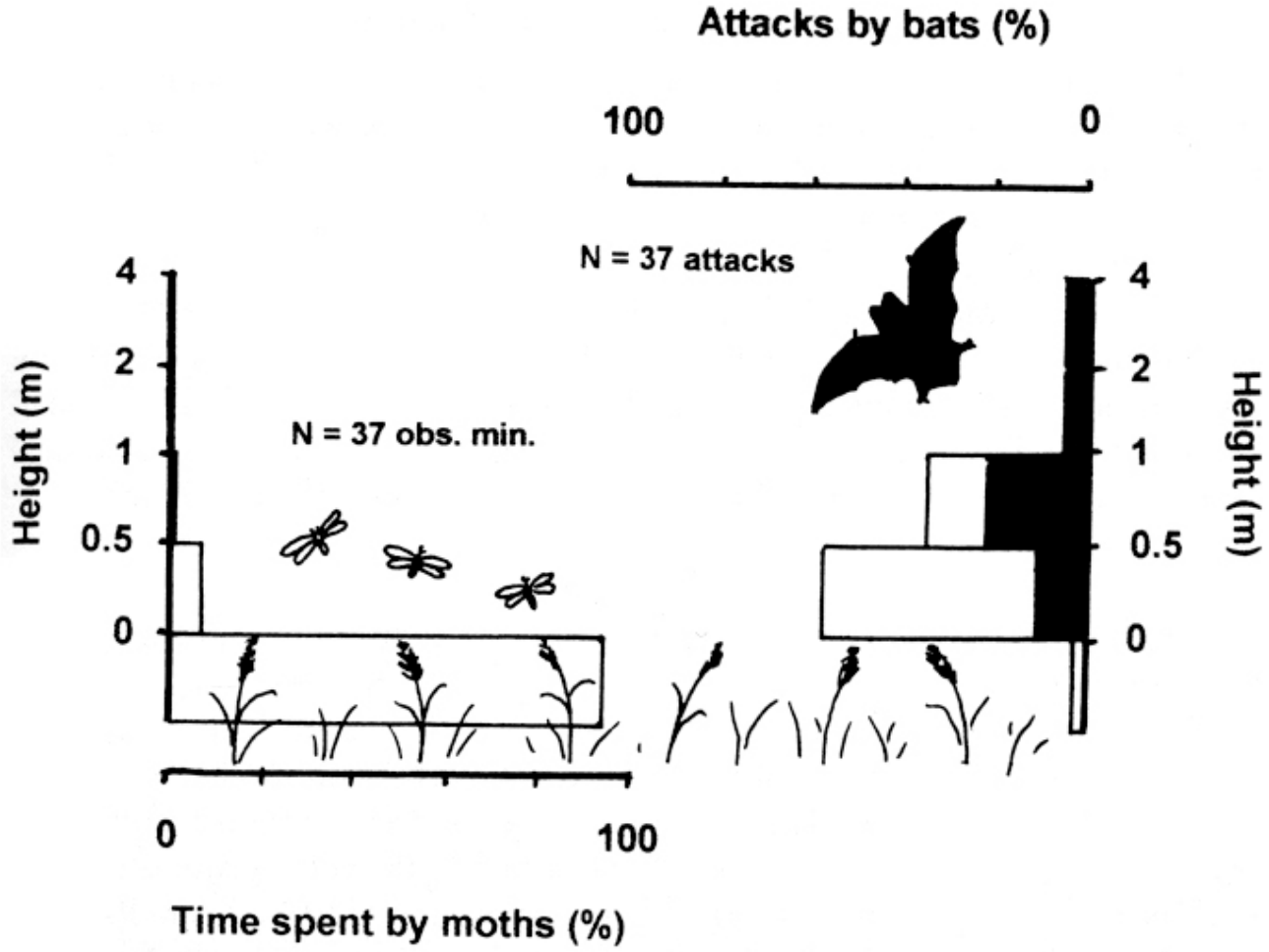
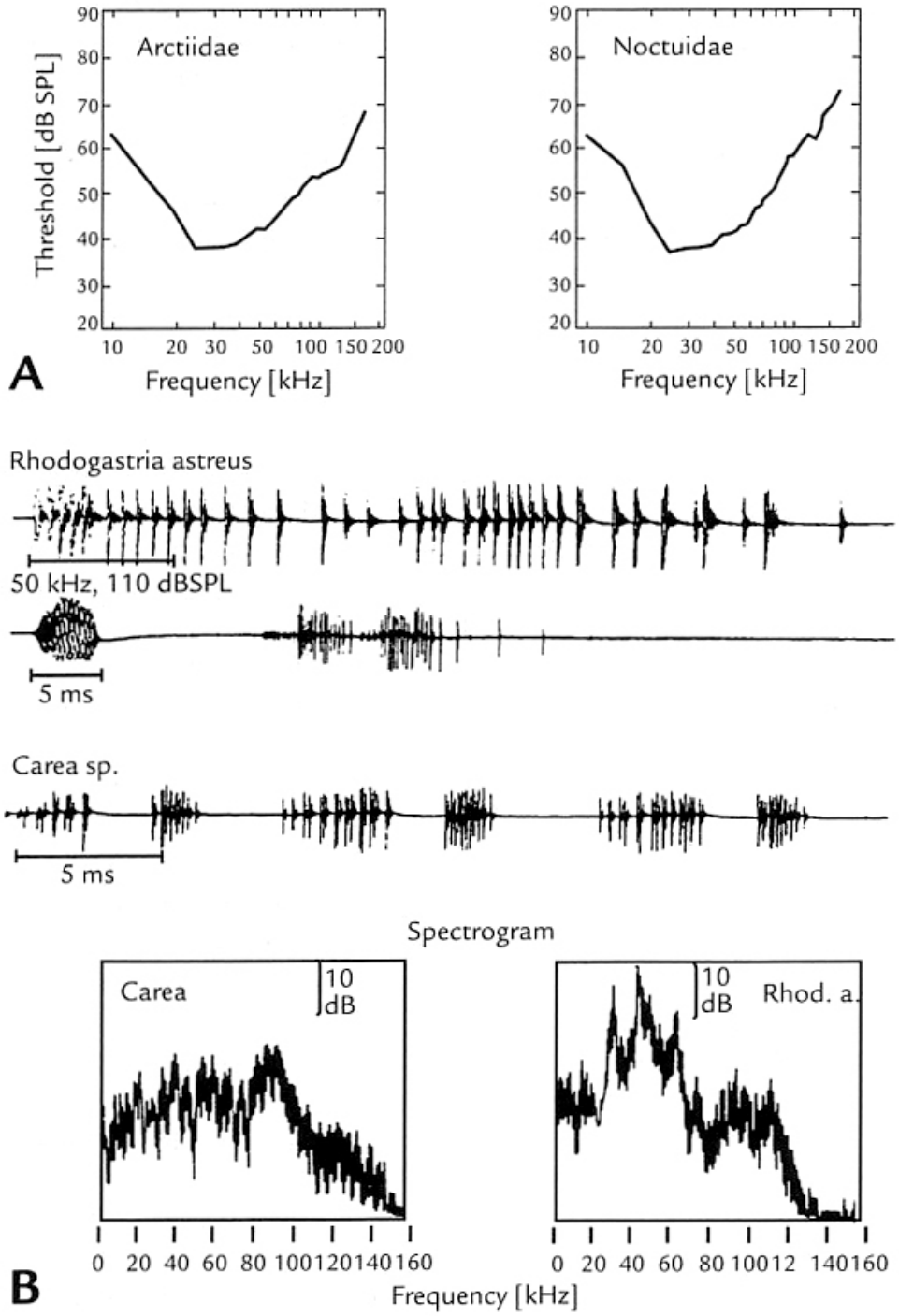


Figure 7.10. The flight height of displaying male ghost swifts, *Hepialus humuli*, over a hayfield in relation to the top of the panicle-bearing grass stems (*left bars*) and the height where the displaying moths were attacked (*right bars*) and caught (*black sections*) by northern bats, *Eptesicus nilssonii*. The focal observations of bats and moths were made separately. (From Rydell [1998], with permission from the Royal Society.)

Moth defensive sounds

- Some moth species produce ultrasound in response to ultrasound.
  - Tiger moths (Arctiidae)
  - some Noctuid moths
  - Nymphalid butterflies

Catocala



Hypotheses for moth sound production

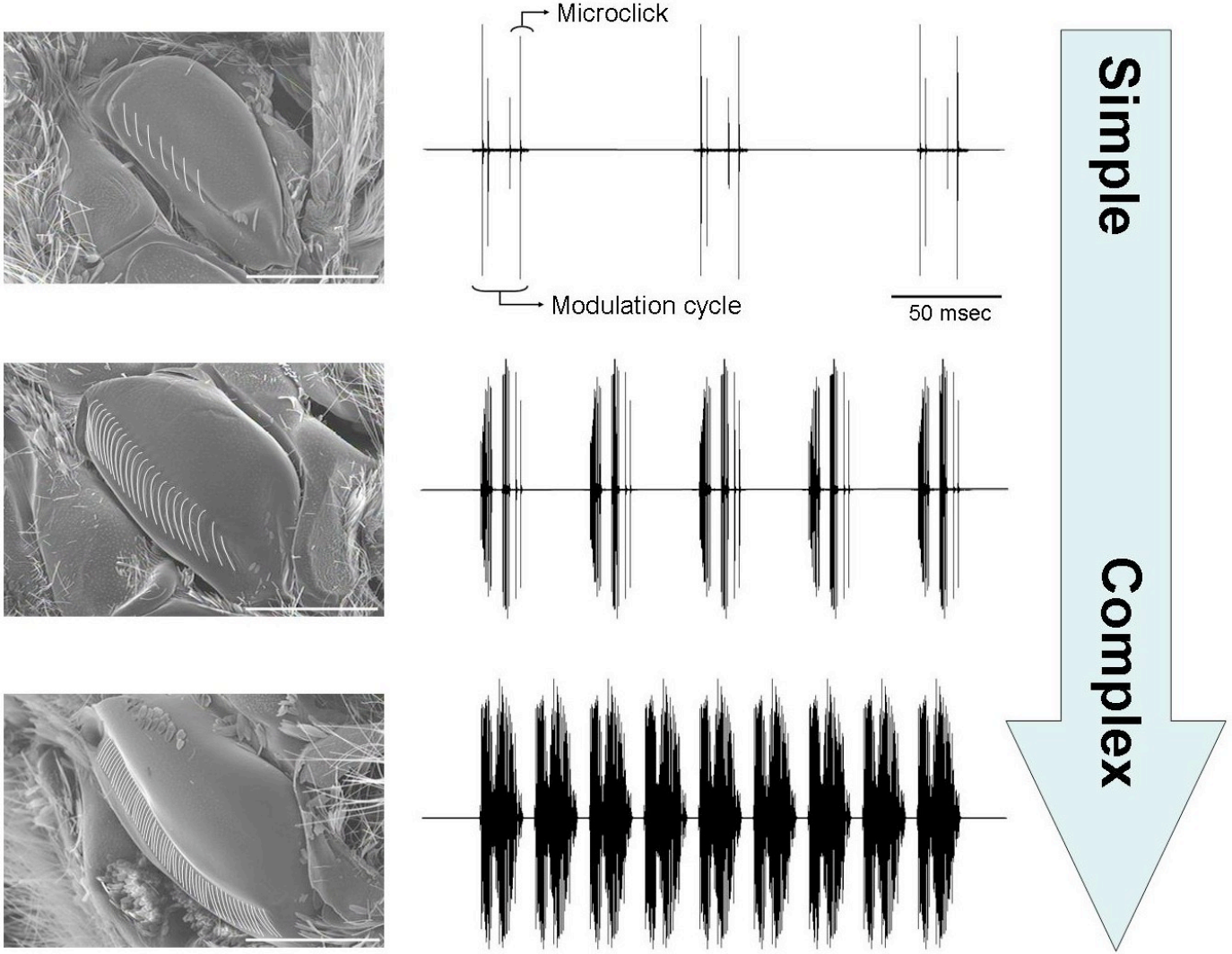
- Aposematism: advertisement of danger
  - bad taste, typically caused by sequestering secondary plant compounds
  - Expect mimicry - no cases yet
- Jamming of bat's sonar

Batesian Mimicry

Viceroy

Monarch

Tymbals and microtymbals in noctuid moths



Bats and flowers

Bat pollination

- Species pollinated by bats
  - 600 in neotropics
  - 160 in paleotropics
- Few are pollinated exclusively by bats
- Location of flower reduces exposure to predators
- Adaptations for bat pollination

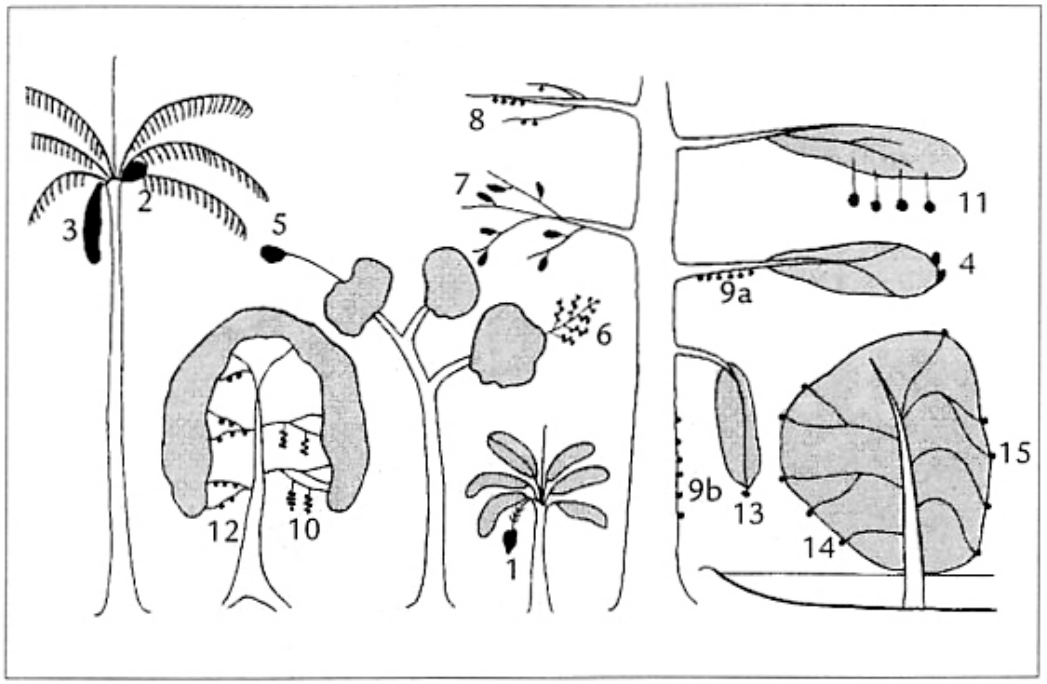


Figure 9.3 The exposure of flowers or flower stalks (black) in Malaysian plants that are visited by bats. Shaded area = foliage. 1, *Musa* species; 2, *Cocos nucifera;* 3, *Arenga* species; 4, *Mangifera* species; 5, *Oroxylum indicum*; 6, *Pajanelia multijuga*; 7, *Bombax valetonii;* 8, *Ceiba pentandra*; 9a,b, *Durio* species; 10, *Barringtonia* species; 11, *Parkia* species; 12, *Syzygium mallaccense;* 13, *Duabanga sonneratioides*; 14, *Sonneratia alba* (*ovata*); 15, *Sonneratia acida*. From Dobat and Peikert-Holle (1985).

Flower adaptations for bats

- Big, erect sturdy white flowers
- Night blooming
- High rate of nectar secretion
- High pollen production
- Often bell-shaped flower
- Intense, unpleasant smell
- Flower continuously for weeks or months

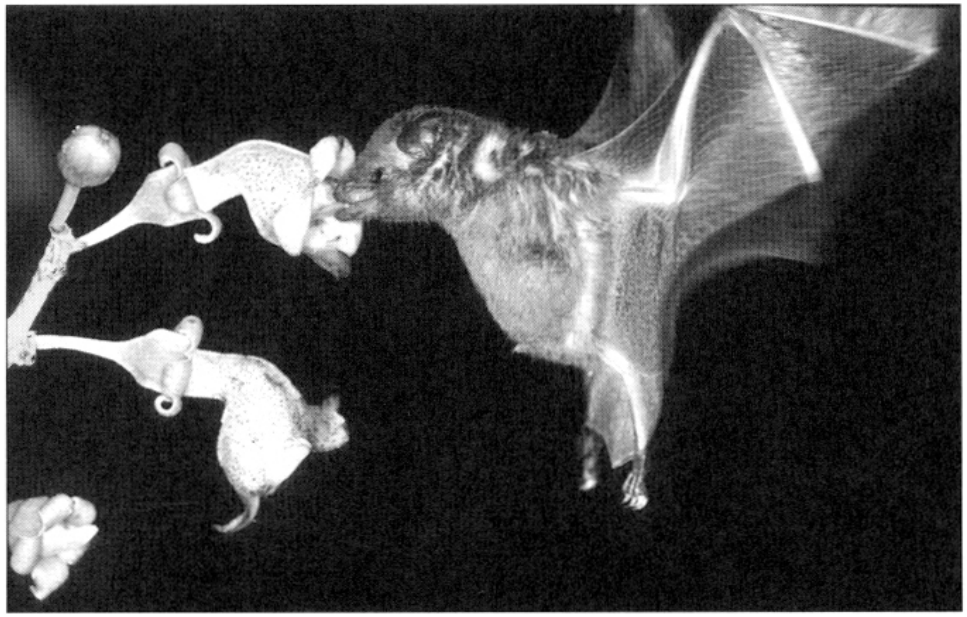


Figure 8.1. The flower of the glossophagine-pollinated *Paliavana prasinata* (Gesneriaceae) is no larger than a head mask for the visiting bat.

Bat flowers often contain sulfur-compounds

Often smell foul - like rotting eggs

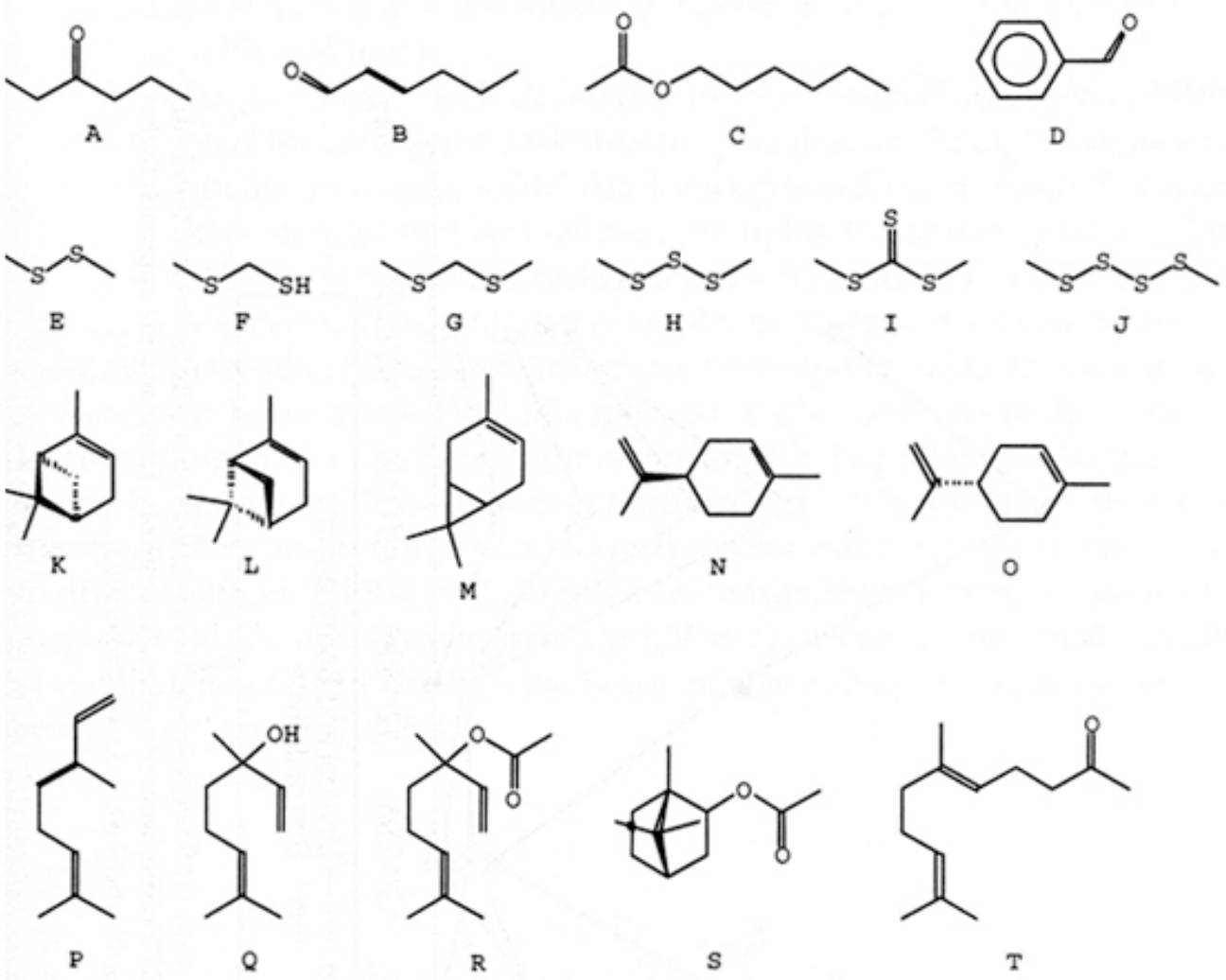
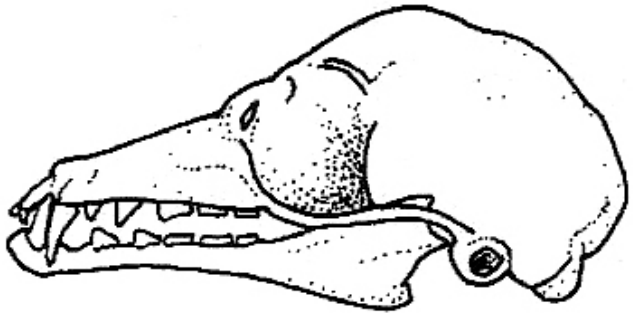


Figure 8.3. Chemical compounds found in the headspace of bat-pollinated flowers. *A*, 3-hexanone; *B*, (E)-2-hexenal; *C*, hexyl acetate; *D*, benzaldehyde; *E*, dimethyl disulphide; *F*, 2-thiapropane-1-thiol; *G*, 2,4 dithiapentane; *H*, dimethyl trisulphide; *I*, dimethyl trithiocarbonate; *J*, dimethyl tetra-sulphide; *K*, (+)-alpha-pinene; *L*, (−)-alpha-Pinene; *M*, delta-3-carene; *N*, (R)-limonene, *O*, (S)-limonene; *P*, ocimene; *Q*, linalool; *R*, linalyl acetate; *S*, bornyl acetate; *T*, geranylacetone (from Helversen et al. 2000).

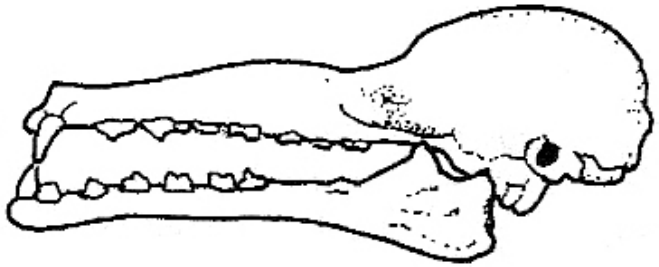
Bat adaptations for pollination

- Two groups: all glossophagine and some pteropodid bats
- Large size (7-35 g) compared to insectivores
- Elongated rostrum
- Can hover
- Good sense of smell
- Good spatial memory
- Attracted by sulfur compounds

Flying Fox



Phyllostomidae



Bats and fruit

Major plant families

–figs and their relatives (Moraceae)

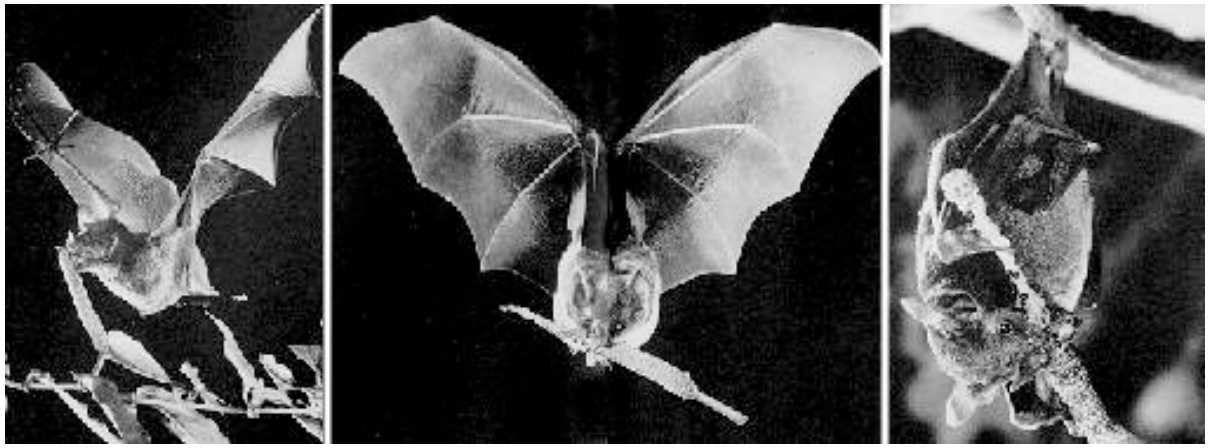
–the chicle family (Sapotaceae)

–myrtle (Myrtaceae)

–palm (Palmae)

–black pepper (Piperaceae)

– tomato families (Solanaceae).



A Seba's Short-tailed Fruit Bat approaches a ripe Piper fruit, plucks it from the plant and flies to a nearby feeding roost. It may eat up to 35 of these fruits in a night, ingesting and dispersing thousands of seeds in the process. PHOTO BY MERLIN D. TUTTLE

Fruit adaptations for dispersal by bats

- Dull coloration (green or brown)
- Fruit displayed in open areas
  - Particularly in new world
- Either many small seeds or large seed with detachable aril (e.g. cashew)
- Some species need to pass through digestive tract to germinate
- Plants grow in disturbed areas

Bats disperse pioneer species of plants

Solanum

Cecropia

Sapacaia nuts - relatives of Brazil nuts

Bat adaptations for frugivory

- Two groups: phyllostomid and pteropodid bats
- Nasal sound production
- High wing-loading
- Good sense of smell
- Large size
- Fast gut passage time
- Dentition capable of cutting into fruits

Bat ectoparasites

Bat flies

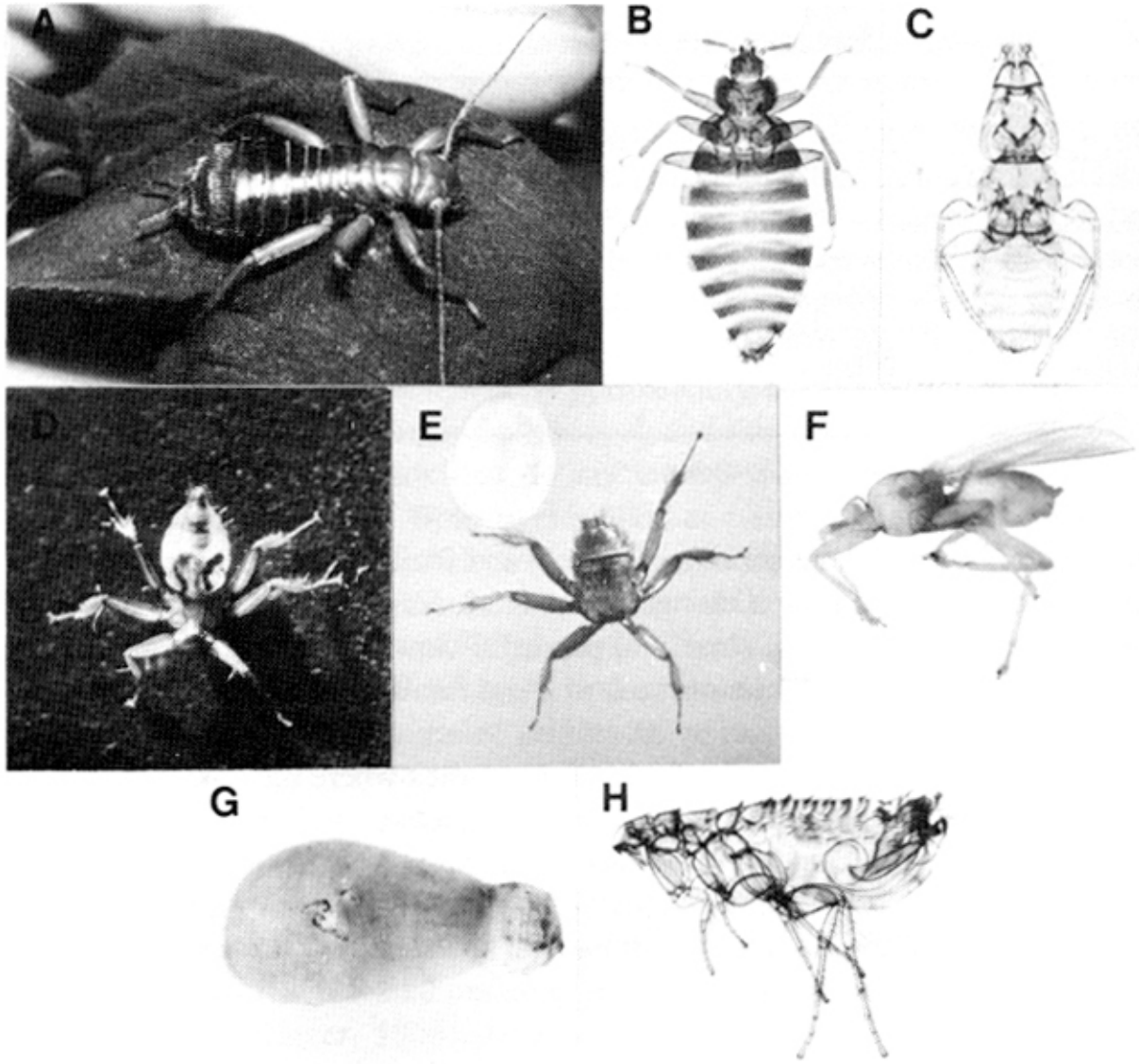


FIGURE 1. Insects ectoparasitic on bats. (A) Arixeniidae: *Arixenia esau* Jordan on the head of *Cheiromeles torquatus* Horsfield. (B) Cimicidae: *Cimex lectularius* L. (C) Polyctenidae: *Eoctenes spasmae* (Waterhouse). (D,E) Nycteribiidae: *Basilia hispida* Theodor, pregnant female (dorsal view) and female immediately after offspring deposition (ventral view). (F) Streblidae: *Brachytarsina amboinensis* Rondani. (G) Streblidae: neosomic female of *Ascodipteron phyllorhinae* Adensamer (anterior to left). (H) Ischnopsyllidae: *Myodopsylla insignis* (Roths.)